INCORPORATION OF AN EMPIRICAL ICING CODE IN A FLIGHT SIMULATOR

PAPER 2003-01-2104

ROBERT J. FLEMMING

MATTHEW T. LUSZCZ

SIKORSKY AIRCRAFT CORPORATION

17 JUNE 2003

CONTENT OF PRESENTATION

- Need for icing simulations
- Description of Sikorsky flight simulators
  - Motion-based, fixed-base, and batch-mode simulators
- Description of empirical code to predict force and moment increments and ice shedding
- Integration of empirical code into flight simulation code
- Sample simulation output
  - Steady-state flight in icing conditions
  - Maneuvering flight in icing conditions

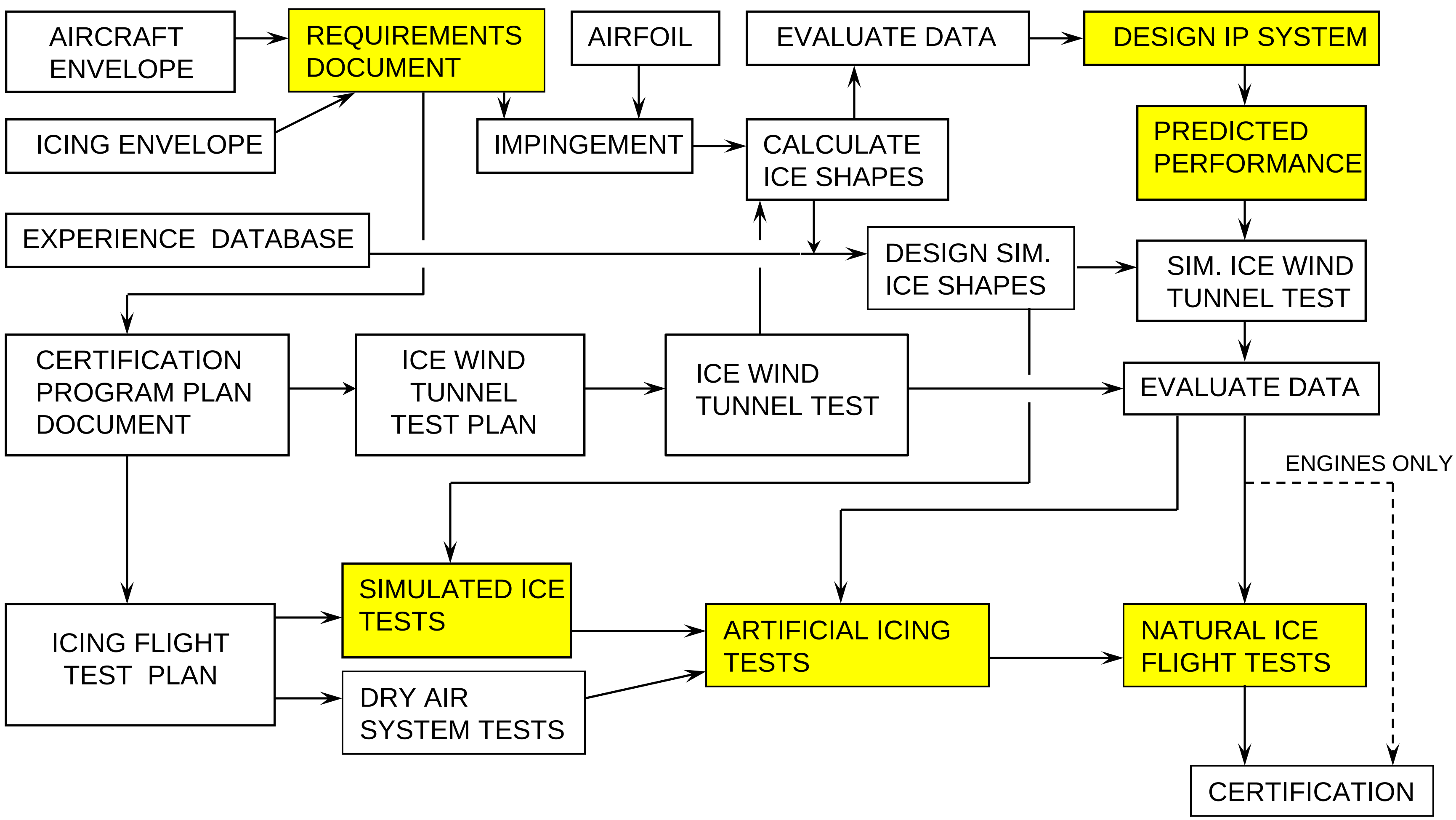
NEED FOR ICING SIMULATIONS

- Can simulate icing effects for a rotorcraft system
  - Predict effects of ice on the helicopter
  - Train pilots for flight in icing conditions
- Prepare for all-weather helicopter flight operations

OTHER ICING FLIGHT SIMULATIONS

- NASA Glenn/WSU/Bihrle Applied Research NASA DHC-6 Twin Otter simulation for a simulated ice shape
  - Calculated ice shapes for the Twin Otter
  - Tested ice shapes in a dry wind tunnel
  - Data incorporated in a flight simulator
  - Effects of icing can be scaled to less severe conditions
- Simulation of the Super Puma for flight in icing conditions
  - Simulator Training Center in Norway, operated by Helicopter Service AS, gives an instructor-controlled severity indication (on a simple scale of 0 to 1, not by OAT and LWC) to the pilots for approximately how icing will be felt in the aircraft
  - Airframe effects simulated include weight and power
  - Rotor effects include weight, power, shedding and vibration

HELICOPTER ICING CERTIFICATION PROCESS

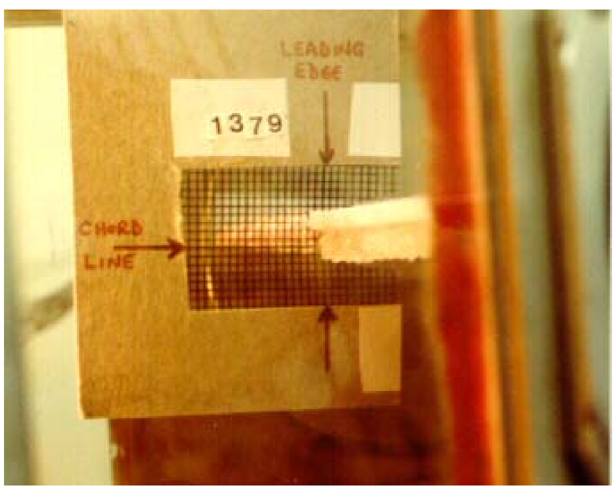


SIKORSKY SIX-DEGREE-OF FREEDOM MOTION-BASED SIMULATOR

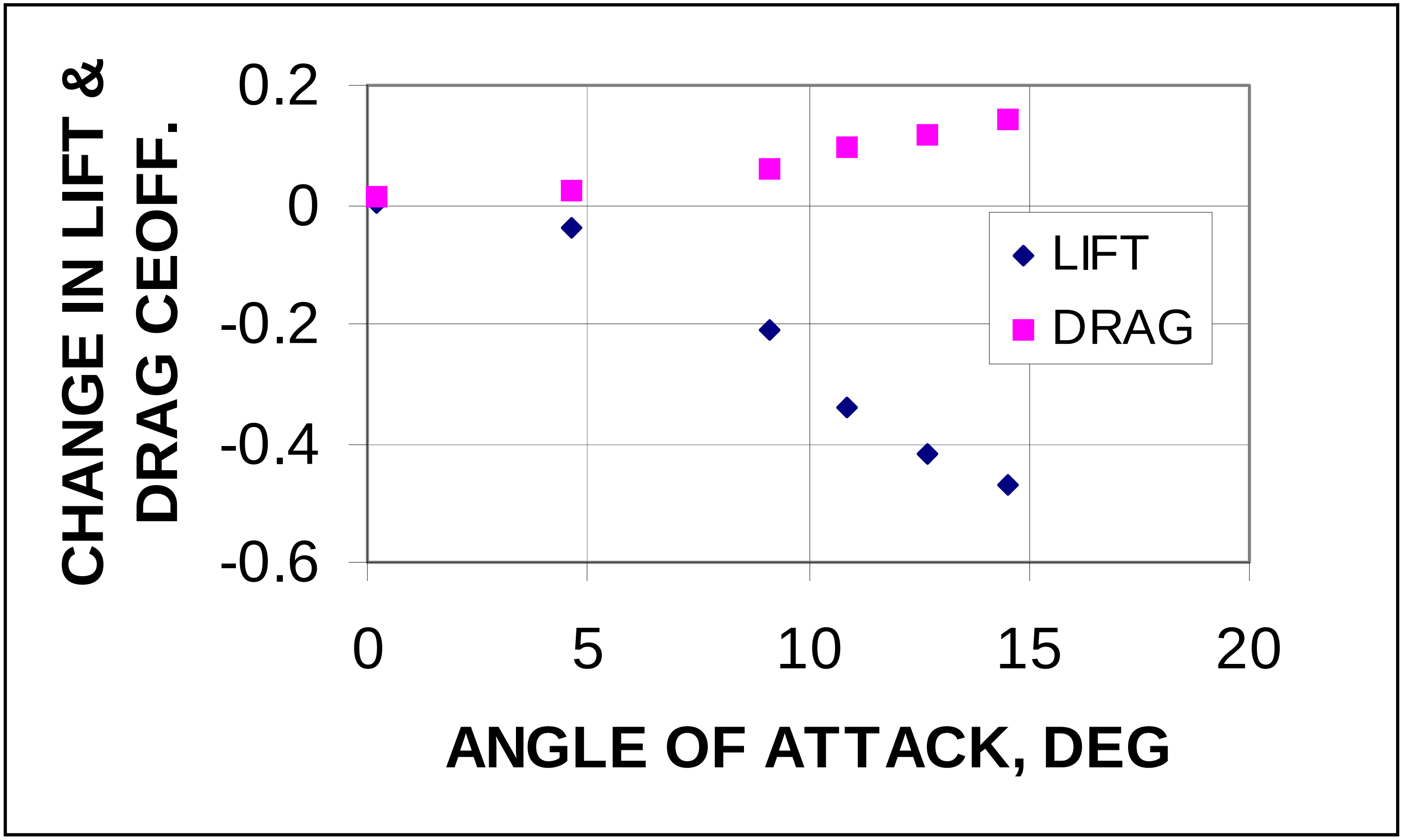
Comanche Simulation

DELICE EMPIRICAL ICING CODE

- Based on 2D and model rotor icing data
  - Prediction of *lift loss* during an icing encounter as a function of LWC, time, AoA, t/c, k_o, and OAT
  - Prediction of the change in *airfoil drag*, as a function of LWC, time, AoA, t/c, LE radius, OAT, and oscillating airfoil effects
  - Prediction of the change in airfoil *pitching moment* as a function of LWC, time, AoA, t/c, LE radius, Mach number, k_o, and OAT
  - Prediction of *shedding effects* as a function of centrifugal force, ice mass, and OAT



EFFECT OF ICING ON 2D AIRFOIL LIFT & DRAG COEFFICIENTS



ROTORCRAFT CODE LOGIC

- Simulator code first computes main rotor, tail rotor and horizontal and vertical tail surface aerodynamic coefficients for clean airfoils (no icing)
  - For the rotor, 2D C_l and C_d calculated at a series of blade radial sections for selected blade azimuthal positions as the blade rotates
    - Icing effects based on average angle of attack and average velocity for each blade section
    - Code determines if ice is shed naturally or if ice is shed through the action of a deice system for each blade section
    - Segment aerodynamics integrated to obtain total aircraft effects
  - For tail surfaces, 2D C_l and C_d calculated and code adds the increment for the effects of ice, with the effect of a deicer if appropriate

POWERED FORCE MODEL IN THE NASA IRT DURING THE 1993 TUNNEL ENTRY

DEICING ALGOITHM

- Computes the time for a deice event for the input icing algorithm
- Algorithm in current rotor simulation based on the BLACK HAWK/S-92A electrothermal heater element on times (= f (OAT) and cycle times (= f (LWC) for a deiced shed or based on a natural shed event (= f (CF, ice mass, OAT) for a single blade section, whichever type of shed event occurs first
- Ice regrowth starts as soon as ice sheds

S-92A ROTOR ICE PROTECTION SYSTEM AS REPRESENTED IN SIMULATION CODE

Main rotor has electrothermal heaters for deicing

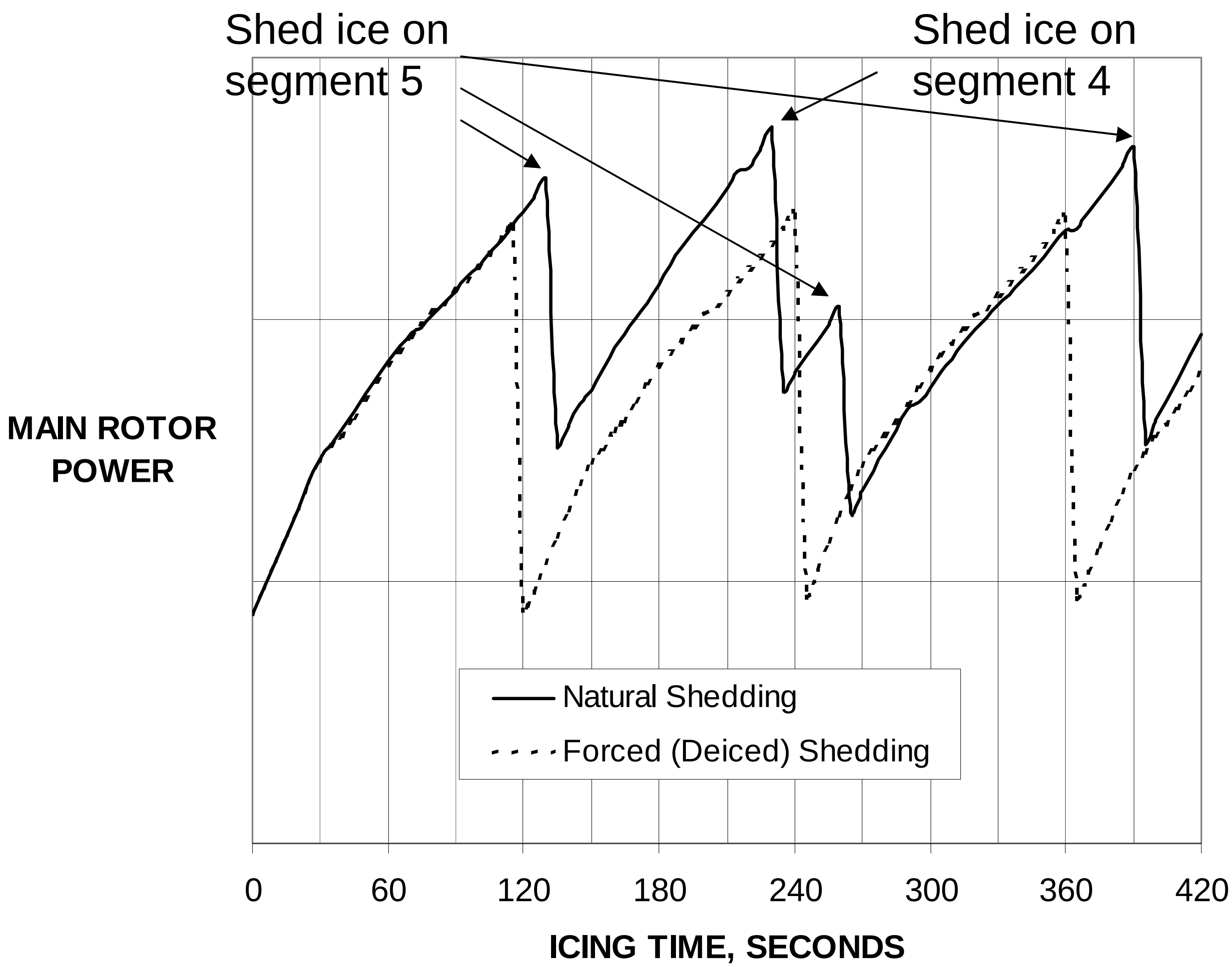
- While S-92A main rotor is deiced by blade pairs with 4 zones per blade, simulation simplified to simultaneous shedding of each of the zones for every blade
- Operation governed by icing severity (LWC) and OAT

- Tail rotor has electrothermal heater elements for deicing
  - Elements operate together on aircraft and in simulation
- Empennage surfaces are not deiced for the S-92A, but code includes the option for use of empennage deicers

SIMULATION SAMPLES

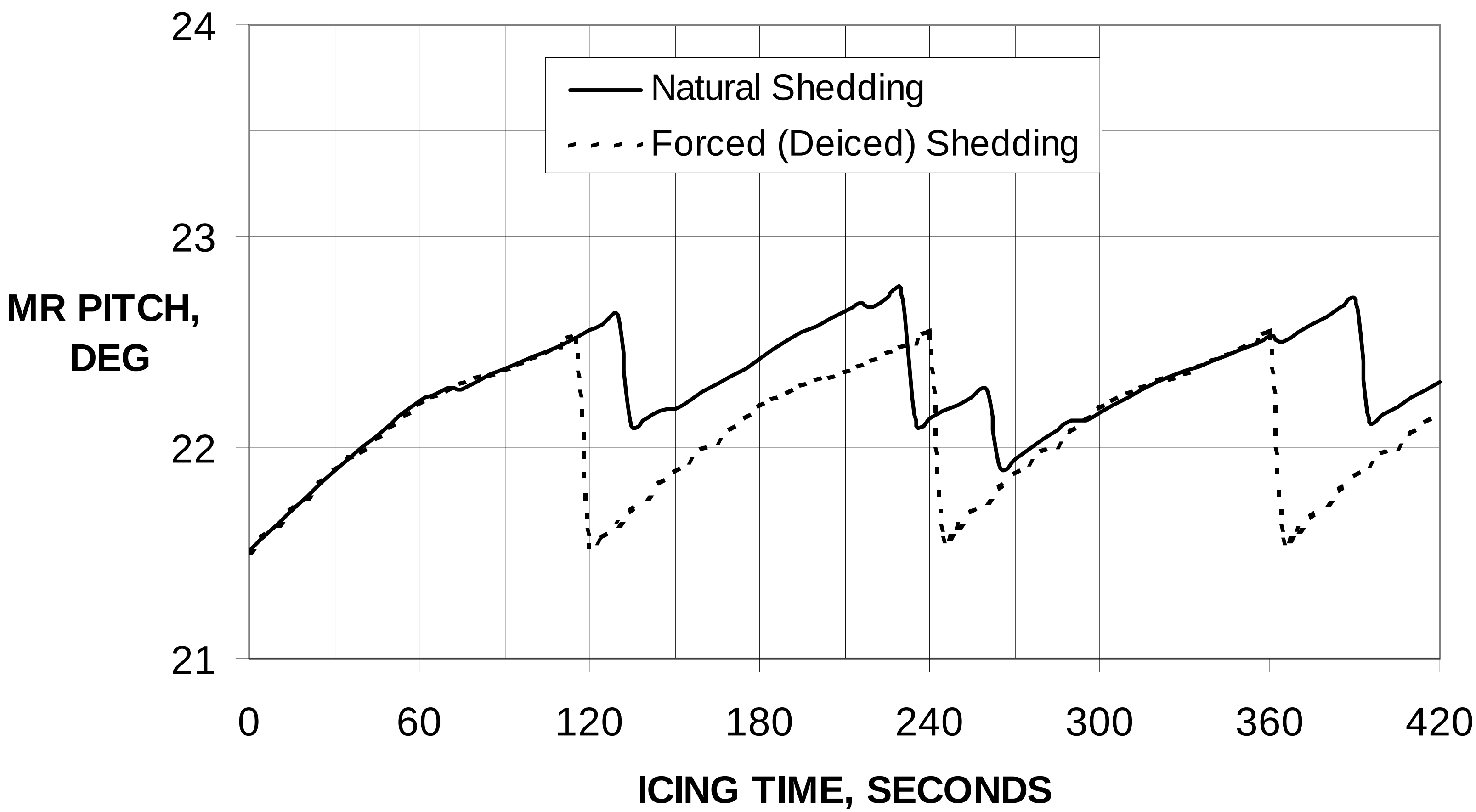
- Steady level flight versus icing time
- Manuevers that start after a specified time of level flight ice accretion
  - A lateral main rotor control step input and reversal
  - A longitudinal main rotor control step input and reversal
  - A pullup manuever using both longitudinal and main rotor collective pitch inputs

EFFECT OF ICE ON MAIN ROTOR POWER

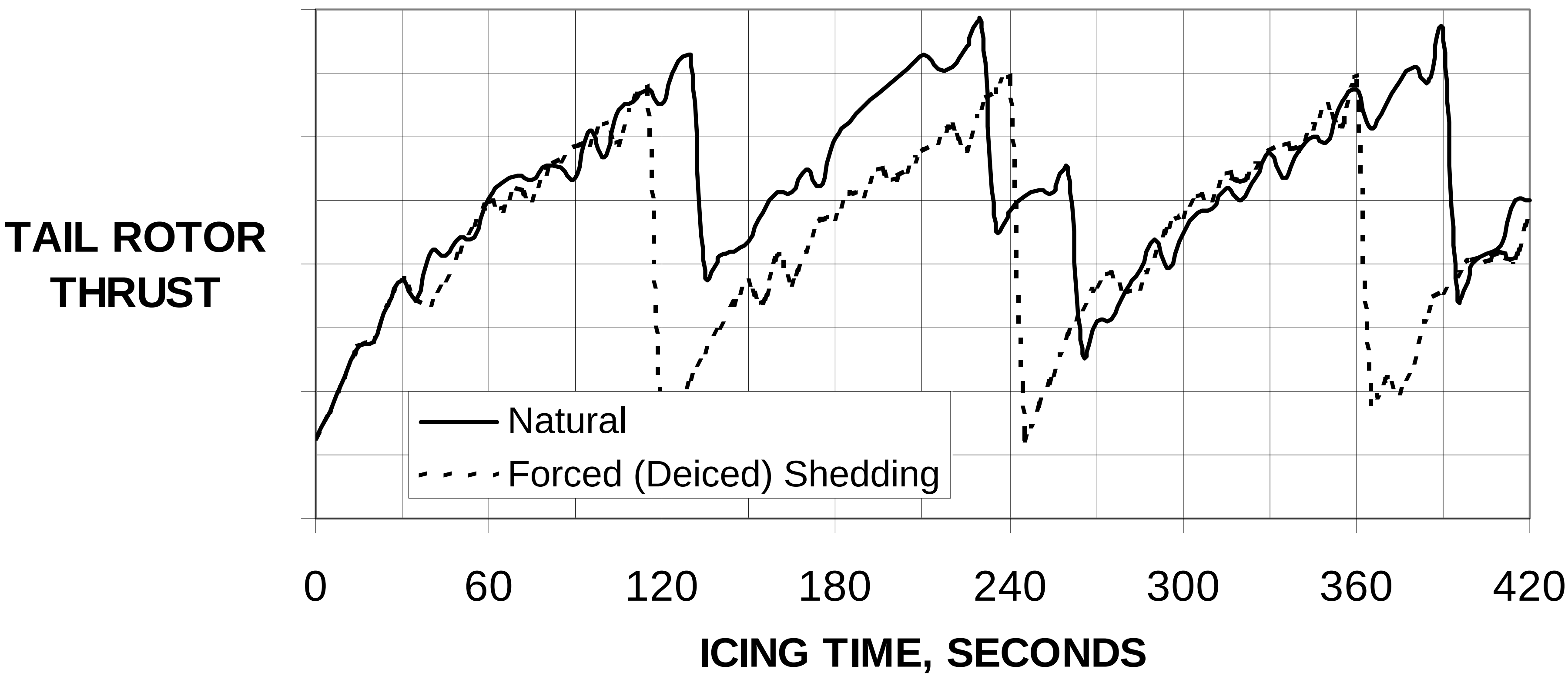


Blade has 5 segments for this sample case, with segment 5 at the blade tip

EFFECT OF ICE ON MAIN ROTOR CONTROL POSITION



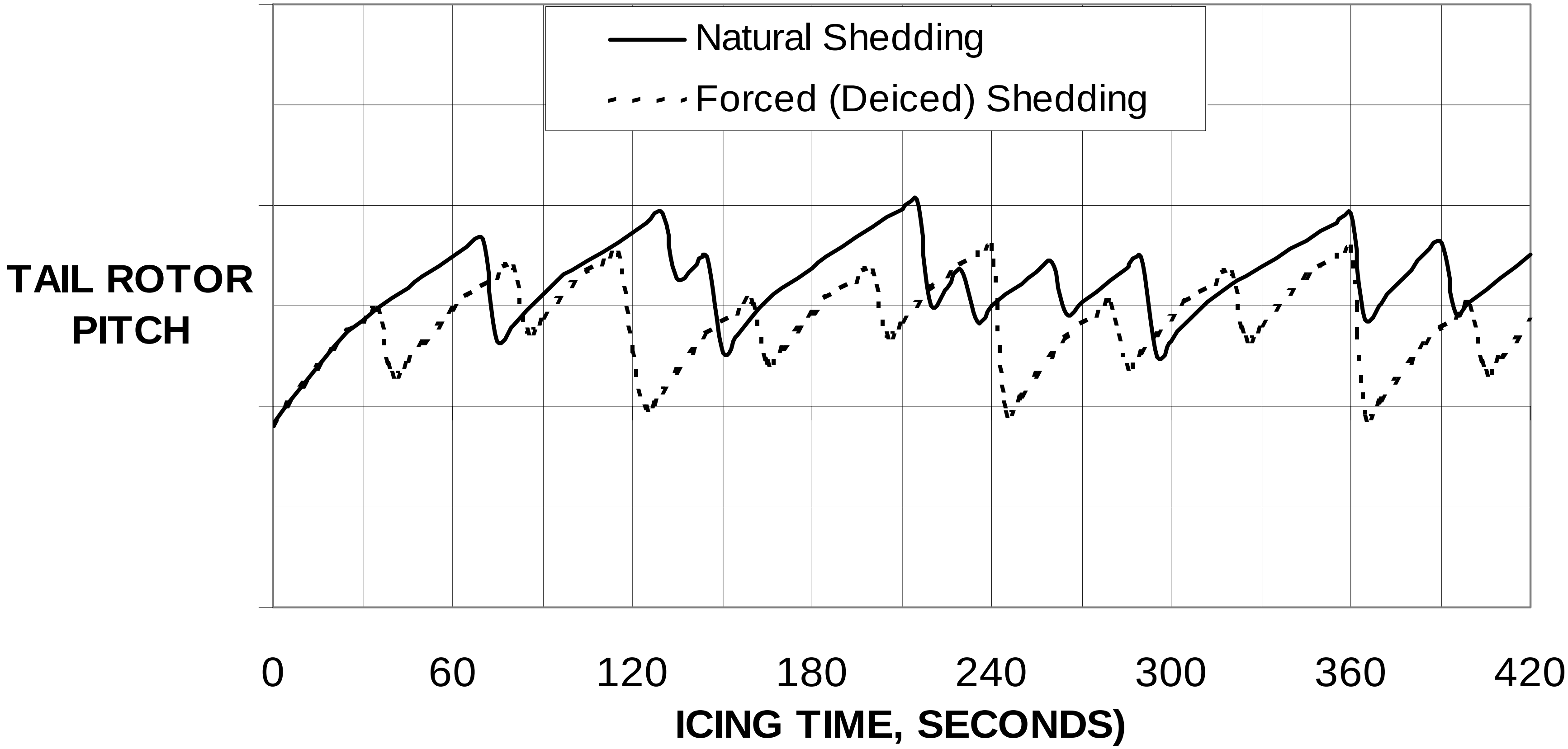
EFFECT OF ICE ON TAIL ROTOR THRUST



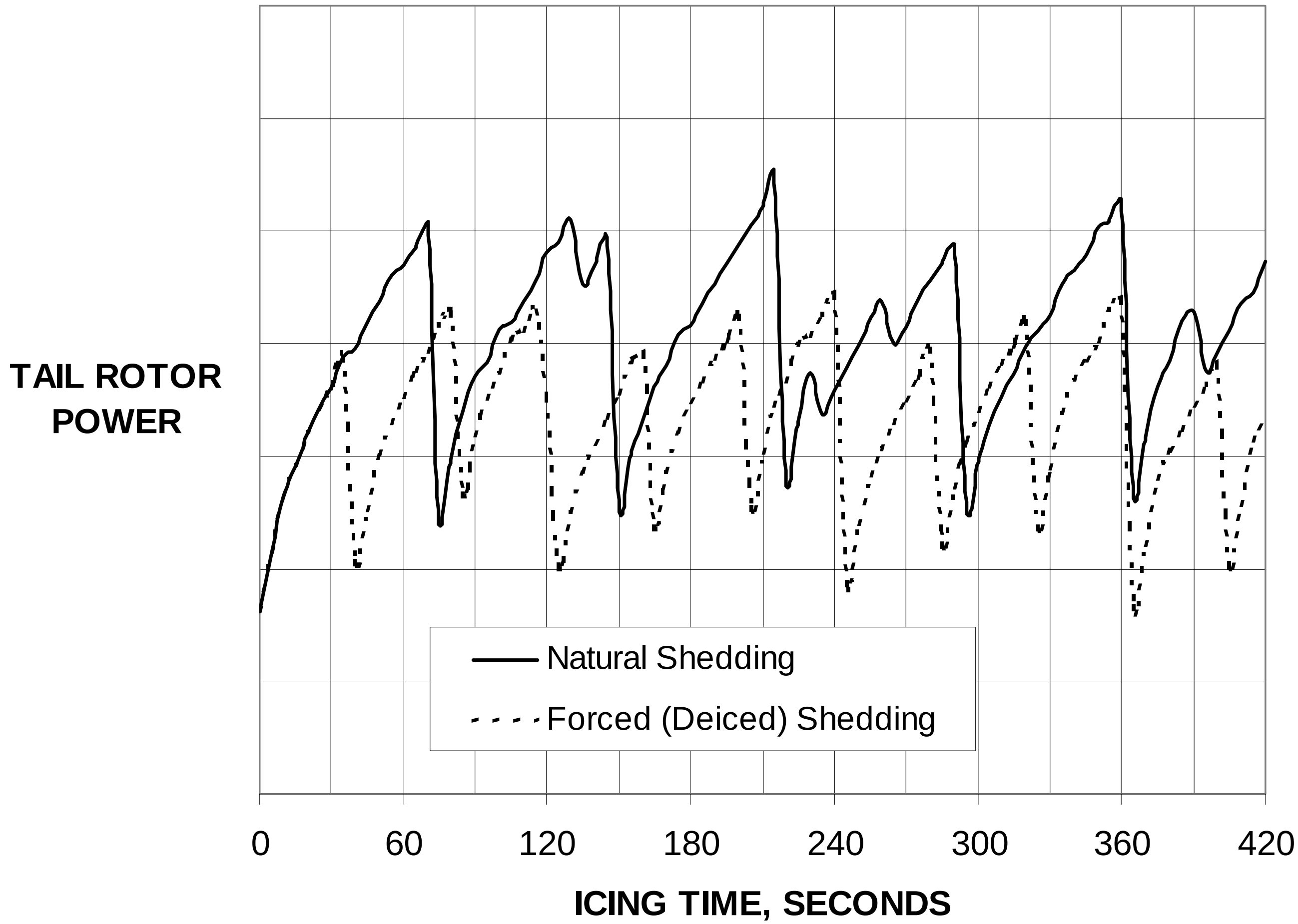
Tail rotor thrust increase = f(main rotor torque increase due to main rotor ice accretion)

EFFECT OF ICE ON TAIL ROTOR BLADE PITCH

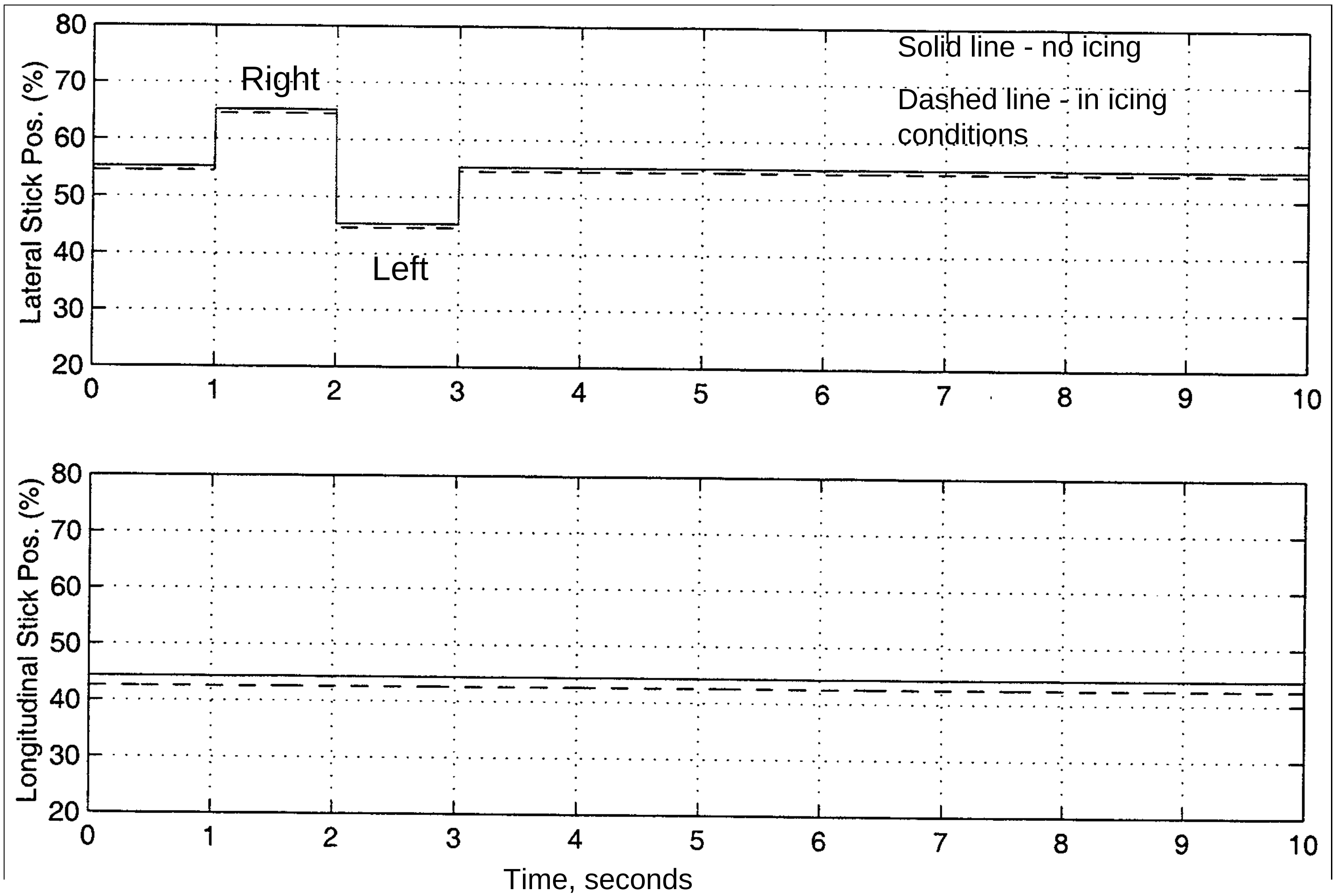
Code predicts control positions



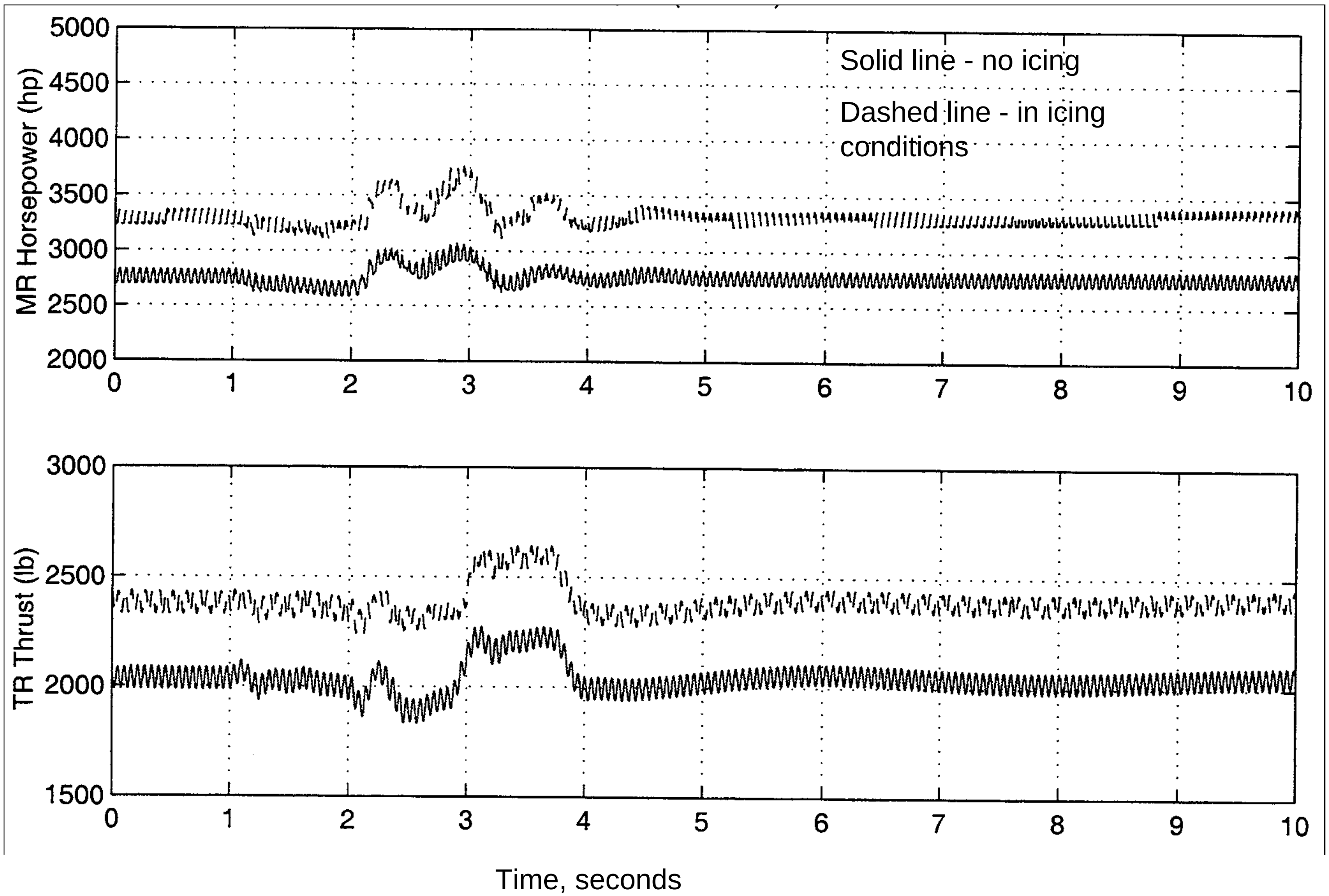
EFFECT OF ICE ON TAIL ROTOR POWER



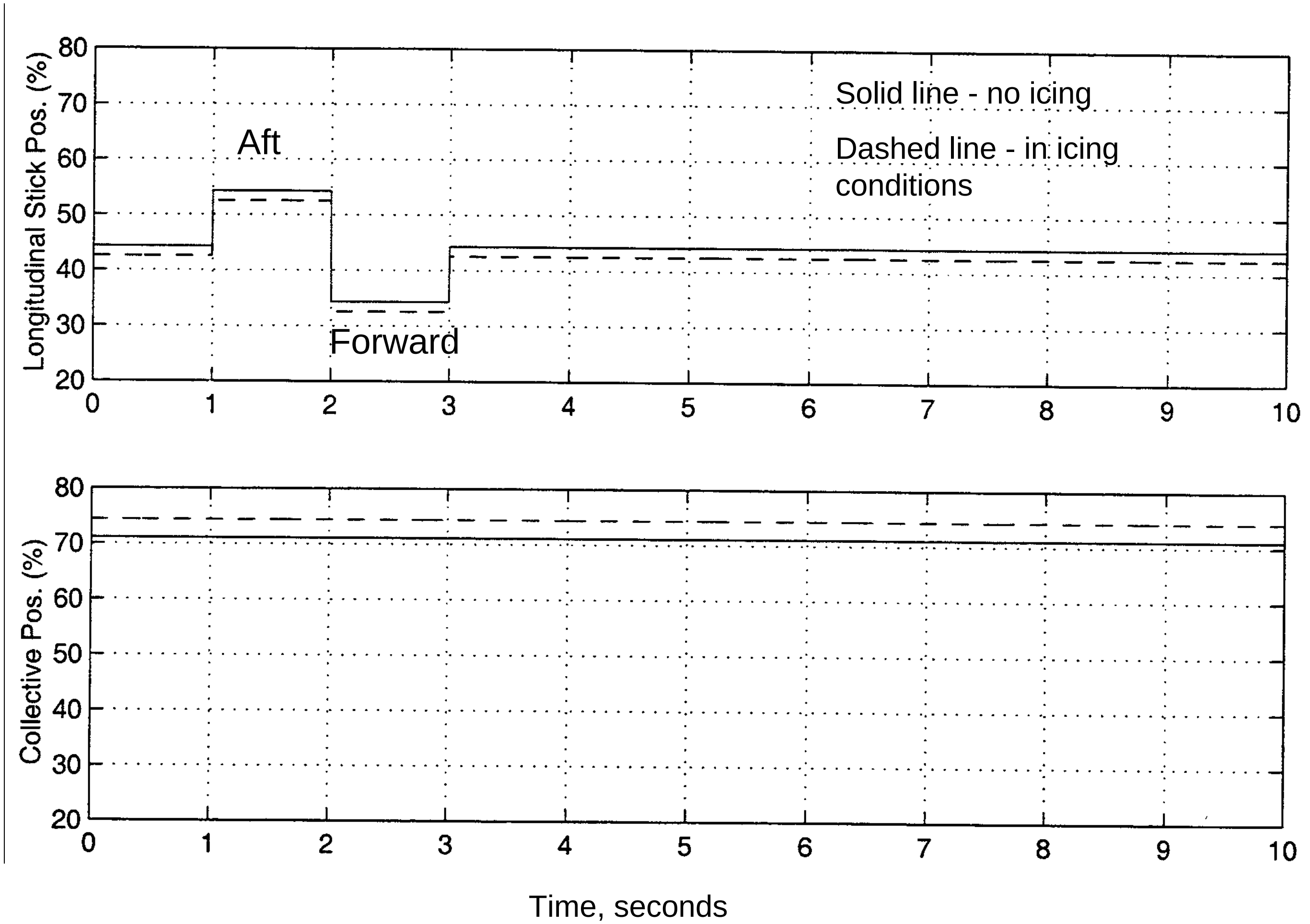
CONTROL INPUT FOR A LATERAL DOUBLET



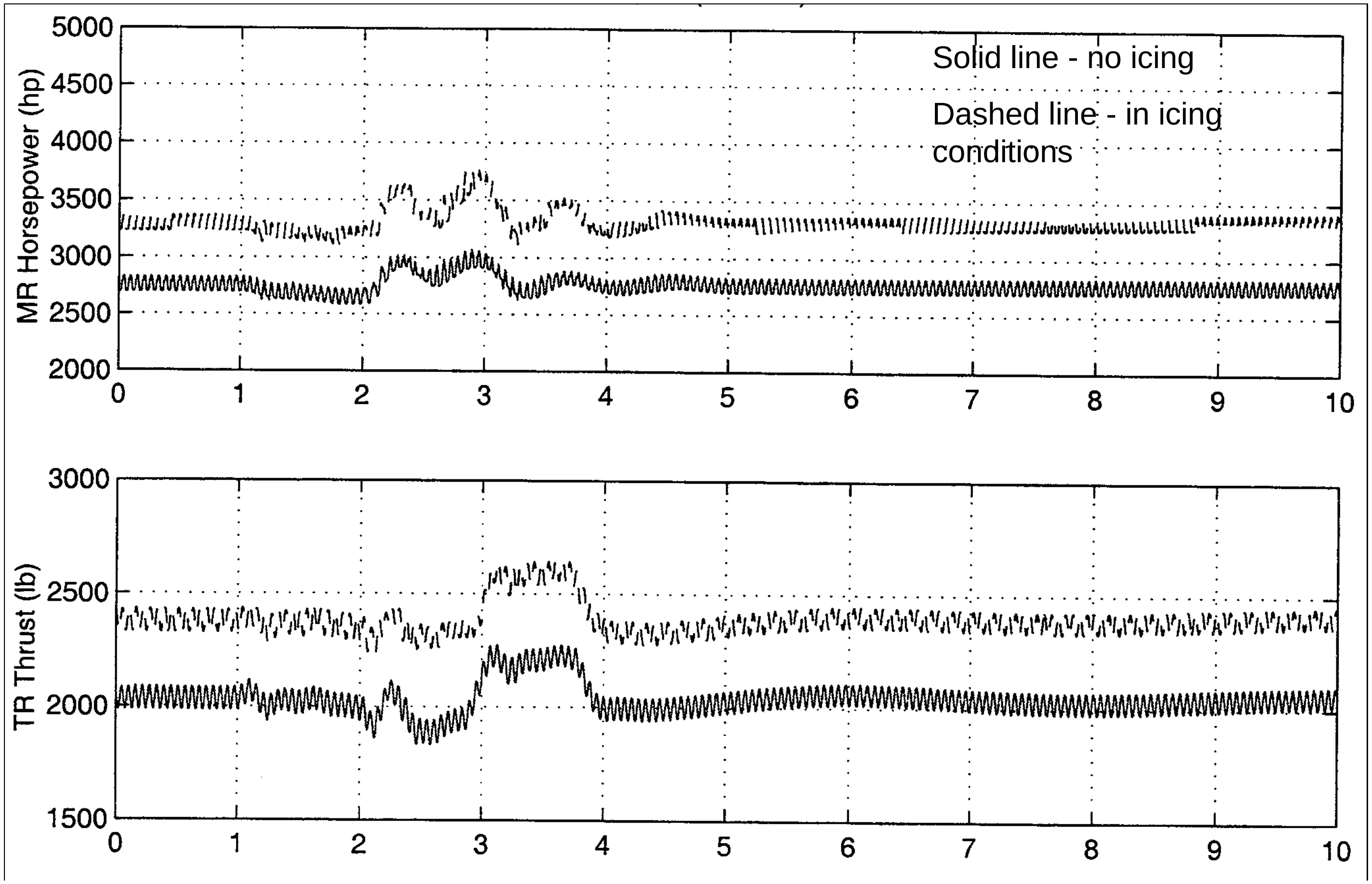
RESPONSE TO A LATERAL DOUBLET



CONTROL INPUT FOR A LONGITUDINAL DOUBLET

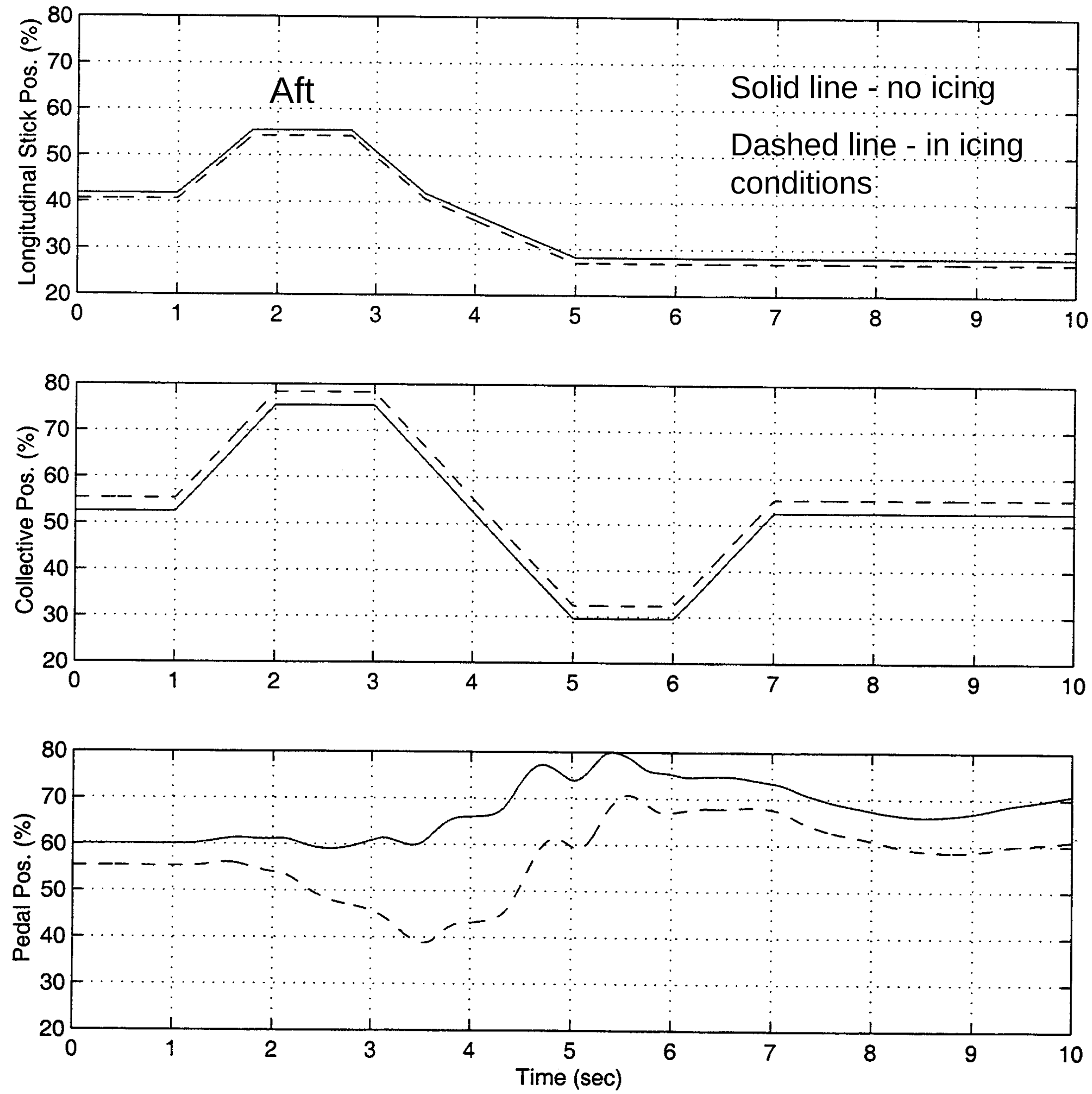


RESPONSE TO A LONGITUDINAL DOUBLET



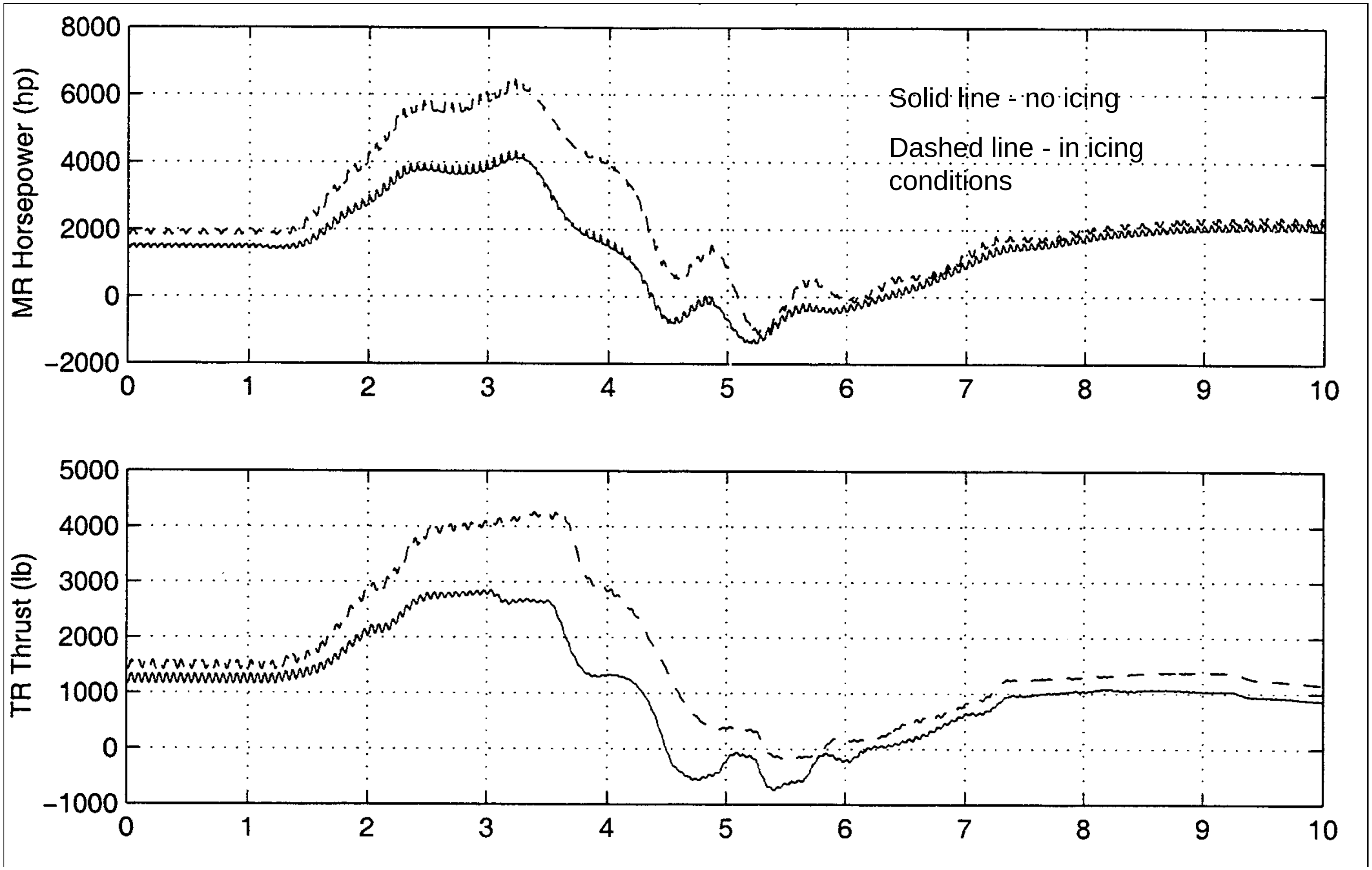
Time, seconds

CONTROL INPUT FOR A PULLUP



RESPONSES DURING A PULLUP

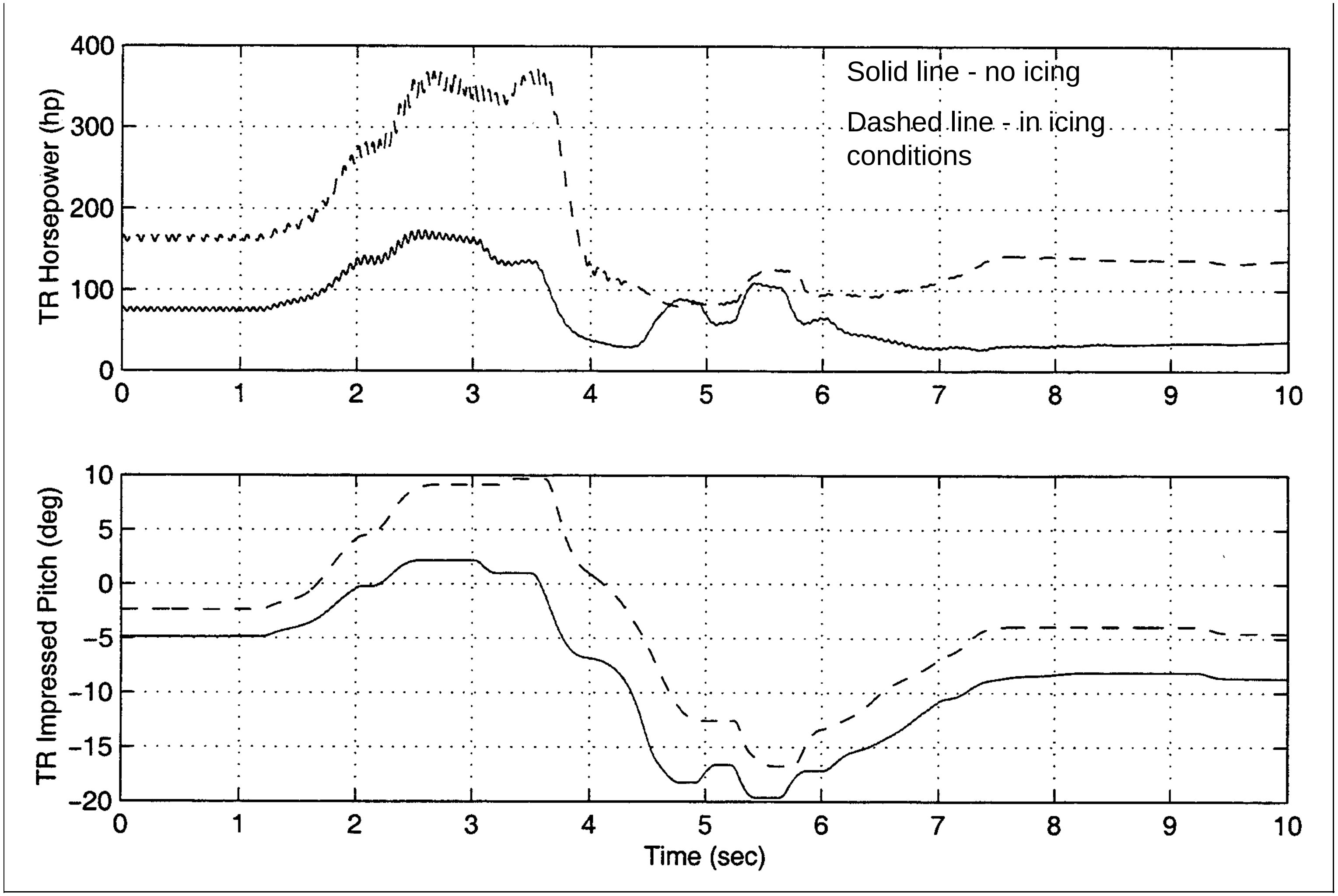
Main Rotor Power and Tail Rotor Thrust



Time, seconds

RESPONSES DURING A PULLUP

Tail Rotor Parameters



CONCLUDING REMARKS

- Sikorsky Aircraft has incorporated an empirical icing code into a flight simulator for the prediction of power required, trimmed thrust, and control positions
- Simulation includes the effects of a deicer as well as natural shedding of ice
- Sikorsky is using computed ice, simulated ice, artificial icing, and natural icing techniques to certify and qualify rotorcraft for flight in icing conditions at a reduced cost and in less time, and is using the simulator for preflight power and control predictions